FATIGUE BEHAVIOR OF ALUMINIUM SILICON CARBIDE (Al-SiC) FOAM

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Certificate

This is to certify that the work contained in this thesis entitled "***Fatigue behavior of Aluminium-Silicon carbide foam***" by **Avanindra Gautam** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree

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Avanindra Gautam

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Abstract

This work describes an investigation on the Fatigue behavior of the Al-SiC foam This is a novel form of cellular solid has a closed cell structure and is made of Aluminium matrix with SiC particles dispersed in it Though some preliminary work has been reported on the mechanical response of this material under indentation and compression testing, little is known about its behavior under fatigue loading Accordingly, this work focuses on the mechanical response of Al-SiC foam under fatigue loading

The fatigue test of this material has been carried out by applying cyclic compressive loading on square shaped specimen The sequence of deformation events observed was elastic deflection of the cell element followed by localized deformation in few cells, the formation of a deformation band, collapse, densification of cells within this band, and gradual spreading of the band through the entire sample The overall deformation and variation in elastic modulus with respect to the number of cycles has been reported are a measure of fatigue induced damage in the material

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CHAPTER 1

INTRODUCTION

1 1 Introduction

This work is concerned with the fatigue behavior of Al-SiC foam Al-SiC is a new class of cellular solid which incorporates a composite cell wall construction In this case, the cell walls comprise of SiC particles embedded in an Al matrix The material has a hierarchy of structural features [1] and the overall mechanical response is therefore a complex interplay of processes taking place at various length scales Although mechanical response under quasi-static load conditions has been reported [1], few studies have looked at the fatigue response The mechanical performance of closed cell Al alloy foams governs their utility in various applications, such as core material for ultra light sandwich panels/shells, as well as crash or blast-absorbing systems From application point of view, it is important to understand the effect of fatigue loading on material response, considerable interest is the phenomenon of damage associated with particle/matrix interface debonding and its effect on the elastic stiffness of the material with increasing number of fatigue cycles

In structural applications of metallic foams, it is necessary to take in account the degradation of strength with cyclic loading Construction parts in vehicles are frequently

subjected to vibrations, and repeated mechanical straining which may lead to fatigue damage of the material [2] Due to potential application of metallic foam under cyclic loading, it is necessary to analyze the cyclic stress-strain response of metallic foams Cyclic stress-strain response of Al-SiC foams has been investigated by uniaxial compression testing The following chapters describe the various investigations we have undertaken, the deformation behavior due to compressive loading and repeated loading and the interpretation of elastic and fatigue behavior

1 2 What is a cellular solid?

A cellular solid is one made up of an interconnected network of solid struts or plates, which form the edges, and faces of cells Such materials are common in nature, wood, cork, coral, sponges are examples Man has made use of these natural cellular materials for centuries The example of large-scale foam in space application involving phenolic foam occurred in 1949 when the foams were used in aircraft carriers [3] More recently man has made his own cellular solids More familiars are the polymeric foams used in everything from disposable coffee cups to the crash padding of an aircraft cockpit Techniques now exist for foaming polymers, metals, ceramics and glasses as well These newer foams are increasingly used, structurally for insulation, as cushioning, and in systems for absorbing the kinetic energy of impacts [4]

In other words, cellular solid means an assembly of cells with solid edges or faces, packed together so that they fill space Depending upon the cell shape and the space that is filled by cells, the cellular solid is classified as follows [4]

- The simplest is a two dimensional array of polygons which pack to fill a plane area like the hexagonal cells of the bee, and for this reason it is called as 2D cellular materials or honeycomb Honeycombs are used for light-weight structural components
- More commonly the cells are the polyhedral, which pack in the three dimensions to fill space, we call such three-dimensional cellular materials as foams

If the solid of which foam is made is contained in the edges itself (so that cells connect through open faces) the foam is said to be open-celled The faces are solid too, so that each cell is sealed off from its neighbours, it is said to be closed-celled and of course, some foams will be partly closed and partly open-celled These types of cellular solids are shown in fig 1 1 Depending upon the cell type, these foams have wider applications The closed cell metallic foam are useful for structural, load-bearing applications, whereas functional applications like sound absorption, fire retardation, heat dissipation, filtration, damping etc require open cell structures

The single most important feature of a cellular solid is its relative density, which is the density of the cellular material to that of the solid material from which the cell walls are made The proper choice of equation for the relative density is depend on the dimensionality of the structure and on whether it has open or closed cells If the cell edge length is l and the cell wall thickness is t, and $t<<l$ that is, the relative density is low then for all closed cell foams with faces of side l and uniform thickness t

$$\frac{\rho^*}{\rho_s} = c\left(\frac{t}{l}\right) \qquad (1)$$

where the 'c' are the numerical constants near the unity, which depend on the details of the cell shape

At low densities, experimental results indicate that the Young's modulus (E) of cellular solids is related to their density (ρ) through the relation [4]

$$\frac{E}{E_S} = C\left(\frac{\rho}{\rho_S}\right)^n = C\rho^n \qquad (2)$$

where E_s and ρ_s are the Young's modulus and density of the solid skeleton and $\rho = \rho / \rho_s$ is the reduced density The constants C and n depend on the microstructure of the solid material Similar relations hold for the bulk and shear moduli, with possibly different values of C and n The value of n generally lies in the range $1 \leq n < 4$, a wide range of properties at a given density The complex dependence of C and n on microstructure is not well understood, and this remains a crucial problem in the ability to predict and optimize the elastic properties of cellular solids

At the local or cellular scale, important variables include the cell character (e g open or closed), the geometrical arrangement of the cell elements (e g angle of intersection), and the shape of the cell struts or walls (e g curvature, and cross-sectional shape and uniformity) At a larger scale, the geometrical arrangement of the cells is also crucial [4] Polymeric foams have the relative density in the range of 0 05-0 02 Cork is about 0 14, and most softwood is between 0 15 and 0 4

1 3 Fabrication of Cellular solid

Almost any material can be foamed Polymers are very common But metals, ceramics, glasses, and even composite can be fabricated into cells [4]

As we described earlier that the cellular solids are of two types i e 2D cellular solids (honeycomb structure) and 3D cellular solids (foams), the method of fabrication of both of these are different

1 3 1 Honeycomb Structure

By pressing the sheet material into a half-hexagonal profile and glue the corrugated sheets together More commonly, glue is laid in parallel strips or flat sheets and the sheet stacked so that the glue bonds them together along the strips The stack of the sheet is pulled apart (expanded) to give honeycomb

Honeycombs can also be cast into moulds, and made by casting They can be made by extrusion

1 3 2 Foams

Foams can be made by using various techniques These may differ depending upon the different type of materials

Polymer Foams:

They are foamed by introducing gas bubbles into the liquid monomer or hot polymers, allowing the bubbles to grow and stabilize, and then solidifying the whole

thing by cross linking or cooling The gas is entrapped either by mechanical stirring or by mixing a blowing agent into the polymers We can produce both open and closed cell structure foams by this method The final structure depends upon the rheology and the surface tension of the fluid in the melts Closed cell foams then sometimes undergoes a further process called reticulation

Polymer foam can be made by subtler methods, one is to precipitate the polymer as a low-density gel in a fluid and then remove the fluid by evaporation

Metallic Foams:

Metallic foams are made by mixing organic beads (carbon for instance) into the metal melt in an inert atmosphere When the metal has cooled and solidified the carbon is burnt off, leaving cellular matrix Powder method can also be used, metal powder mixed with an inert filler (carbon) can be compacted and sintered After sintering the carbon component is leached out They can also be made by direct foaming, by punching dimples on to sheets and bonding the sheets together for instances

Glass foams:

They are made by the methods, which are quite similar to, those used for polymers principally by the use of blowing agents Ceramic foams are made by infiltrating polymer foam with a slip (a fine slurry of ceramic in water or other fluid), when the aggregate is fired the slip bond to give an image of original foams Carbon foams can be made by graphitizing polymeric foams in a carefully controlled environment

More recently, new forms of foam structures have been developed with highly oriented porosity, [5] as well as those with a composite microstructure [6]

1 3 Application of Cellular Solids

The cellular solids are used in various fields, the major areas of application of foams are as follows [4]

Thermal insulation:

The largest application for polymeric and glass foams is as thermal insulation Products as humble as disposable coffee-cups and as elaborate as insulation of rocket booster for the space shuttle, exploit the low thermal conductivity of foams, and further low thermal mass make them immensely useful for so many applications

Packaging:

An effective package must absorb the impacts or of forces generated by deceleration without subjecting the content to damaging stresses Foams are very much suited for this since their strength can be adjusted over a wide range by controlling its relative density Further they can undergo large compressive strains at almost constant stress, so that large amounts of energy can be absorbed They also reduce the weight of packaging unit further reducing the handling cost and shipping cost

Structural:

Many structural materials are cellular solids, wood, cancellous bone and coral all support large static and cyclic loads for long period of time Foams are also used as sandwich panels where weight is critical

Buoyancy:

Closed cell plastic foams are extensively used as supports for floating structures and as flotation in boats Foams are much more damage tolerant than flotation bags or chambers because of their closed cells they can retain their buoyancy even when extensively damaged

Other Applications:

They can be used as a filter, carriers for inks, dyes, lubricants, stoppers for bottles, non-slip surface for trays, tables or floors and even for enzymes for chemical processing Due to large damping capacity they can be used as to line ceiling and walls of cinema halls

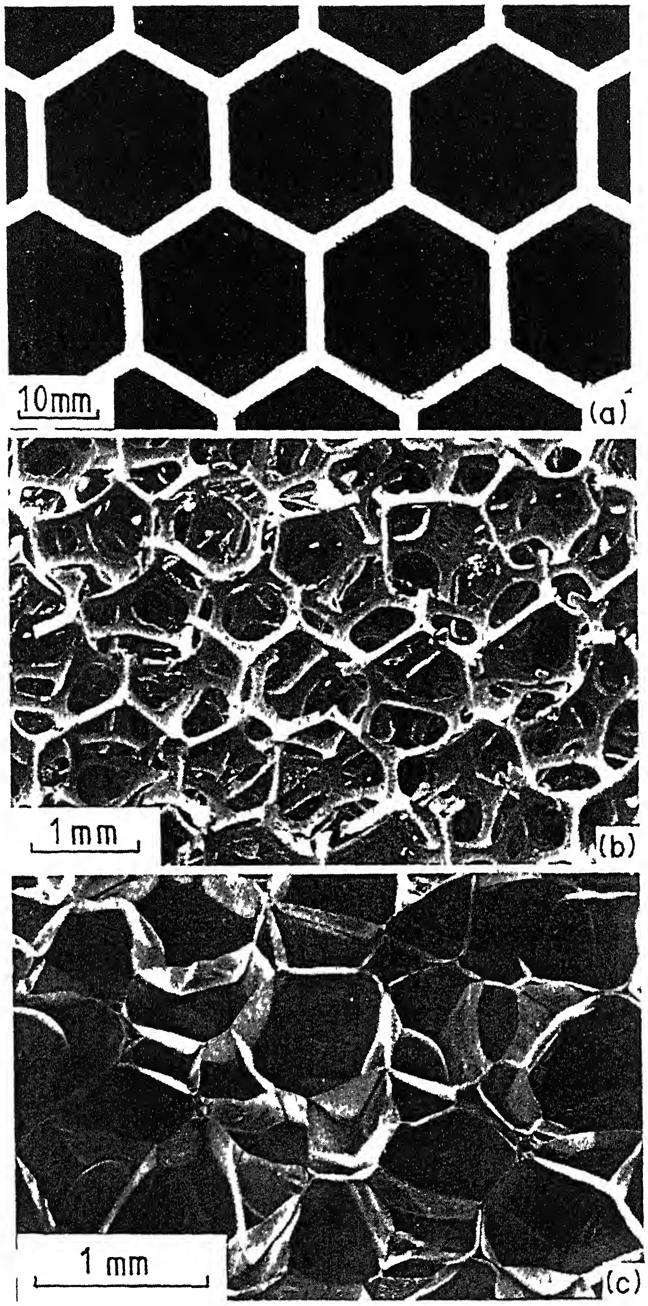


Fig 1 1 Structure of cellular solids (a) 2-D honeycomb (b) 3-D foam with open cells (c) 3-D foam with closed cells

CHAPTER 2

STRUCTURE AND MECHANICAL RESPONSE OF METALLIC FOAMS

The mechanical response of cellular solids is affected, not just by the properties of cell wall material but also by the macroscopic cell structure Accordingly, a brief overview of structure and mechanical behavior of metallic foam is presented in this chapter

2 1 Characterizing of Cellular Solids (Foams)

The parameters generally used for characterization of cellular solids are as follows [4]

- Material – of which the foam is made of
- Structure -- Open or closed cell
- Relative density
- Edge connectivity and face connectivity –Average number of edges, which meet at any vertex

- Mean number of edges per face and number of faces per cell
- Cell shape
- Cell edge thickness and cell face thickness
- Fraction of material in cell edges
- Shape anisotropy ratios
- Distribution in cell size

2 2 Structure of Cellular Solids

A hierarchy of structure exists in the cellular solids and these can be grouped into two categories [1] -

- Cell (geometrical) structure
- Material structure

The cell structure includes cell shape and size, distribution in cell size and defects and flaws in the cell structure

The material features include the nature and detailed microstructure of the cell wall material

The overall mechanical response of such solids is determined by the interaction between these factors for a given loading geometry

For the macroscopic and geometrical structure, Al-SiC foam has a closed cell structure (fig2 1), the shape of cells is found to be closely related to the relative density of the foam Foam with the high relative density consists of spherical cavities embedded in the metallic matrix For foams with low relative density, individual cells can feel the presence of the neighbouring cells during solidification

In general, the cells are made of cell edges (struts) and cell walls (thin membranes) providing a closed cell structure In foams with relative densities 0 04 and 0 1, the cells are polyhedral in shape The cell edges and the walls have curvature indicating the cells have solidified before equilibrium configuration could have been reached The edges have the continuously decreasing area from the nodal points towards their mid span The walls are

often wrinkled indicating that the surface tension forces have not played much roles in shaping the cells

In foams with relative density 0 2 have more complex structure They have a mixture of spherical cavities and other polyhedral shapes The spherical cavities are usually very small and lie in the cell edges, and the cell edges are much thicker than the walls As far as the microstructure is concerned, the Al-SiC foam has a heterogeneous SiC particle distribution

2 3 Deformation Mechanisms in foams

Foams show the linear elasticity at low stresses followed by a long collapse plateau, truncated by a regime of densification in which the stress rises steeply shown in fig 2 2

Linear elasticity is controlled by cell wall bending and, if the cells are closed, then controlled by both cell wall bending and cell face stretching, young's modulus is the initial slope of the stress-strain curve

In case of compression loading shown in fig 2 2, the plateau is associated with collapse of the cells-by elastic buckling in elastomeric foams, by the formation of plastic hinges in foam, which yields such as metals, and by brittle crushing in brittle foam such as ceramic When the cells have almost completely collapsed opposing cell walls touch, and further strain compresses the solid itself, giving the final region of rapidly increasing stress Increasing the relative density of the foam increases young's modulus, raises the plateau stress and reduces the strain at which densification starts

2 4 Mechanical Properties of Foams in compression

The efficient use of foam requires a detailed understanding of their mechanical behavior Often the primary function is mechanical Even for application where the primary use is not of mechanical type like thermal insulation, floatation or filter, the strength and fracture behavior are still important

Most application of foams causes them to load in compression Due to compression loading, the deformation takes place in various stages These stages comprise linear or nonlinear deformation followed by plastic collapse or brittle crushing depending upon the type of material used for foam

- **Linear elasticity:**

The mechanism of linear elasticity depends on whether the cells are open or closed In open-cell foams, cell walls bend when the load is applied (figure 2 3a) Closed-cell foams are more complicated (figure 2 3b), if the membranes that form the cell faces do not rupture, then there are two further important contributions to the modulus The first arises because any deformation stretches these membranes, so that their tensile stiffness contributes to the stiffness of the foam itself The second is caused by the compression of the cell fluid, which is trapped within the cells

- **Non-linear elasticity and densification:**

Linear elasticity is limited to small strains, say up to 5% or less Elastomeric foams can be stretched or compressed to a much larger extent, with the deformation still recoverable but non-linear In compression the stress-strain curve shows an extensive plateau at a stress σ, the elastic collapse stress (fig 2 2), and this stress is very important in the design of cushions, packaging and foam-based system for damping vibration Elastic buckling of cell walls causes elastic collapse in foams The elastic collapse stress behavior depends on whether the foam has open or closed cells Open cell foams collapse almost at constant load, giving a long plateau In closed cell foams, with the membrane stresses that appear in the cell faces, give a stress strain curve that rises with the strain

Densification occurs at large compressive strains, the opposing walls of the cells crush together and the cell wall material itself is compressed When this happens the stress-strain curve rises steeply

- **Plastic collapse and densification:**

Foams made from materials, which have a plastic yield point collapse plastically when loaded beyond the linear-elastic regime Plastic collapse property is exploited in foams for crash protection and energy absorption systems Plastic collapse in open cell foam occurs when the moment exerted on the cell walls exceeds the fully plastic moment creating plastic hinges In closed cell foam plastic collapse load may be affected by the stretching as well as the bending of the cell walls, and by the presence of a fluid within the cells

As with elastic collapse, large plastic strains in compression cause the cells to crush together, and make the stress-strain curve rises steeply to a limiting strain

- **Plastic indentation:**

Foams change their volume when compressed The cells of foam collapse as the foam is squeezed, so the axial compression produces very little lateral spreading once collapse has begun Because of this the indentation hardness of the foam is less than that of a dense solid with the same yield strength Indentation hardness is an important design parameter particularly for packaging application Indentation test on the brittle foam shows unusual characteristics The indentation pressure strongly depends upon the size of the indenter

- **Brittle crushing strength and densification:**

Brittle foams collapsed by another mechanism brittle crushing The low crushing strength of the foams can cause problem when they are used as insulation, which must also support load

- **Fatigue:**

Repeated compression damages some flexible foams is a drawback when they are used for cushion or seat padding Flexible polyurethane foam, particularly, suffers from

"flex-fatigue" a loss of strength and a permanent decrease in volume, caused due to changes in chemical structure

Fracture occurs by two different mechanisms Firstly, the cell walls fracture transversally and crack propagates by breaking walls Secondly, the crack advances longitudinally in the walls, splitting them into two [7] In aluminium foams, structural collapse occurs mostly by buckling of cell walls even at low strains [8] Aluminium foams have almost identical strengths in uniaxial tension and compression [9] Generally, the deformation concentrates in weak or over-stressed regions and properties to adjacent regions in the form of a deformation band This type of behavior has been experimentally observed in compression of common cellular materials [10] This localization of deformation and its propagation in the form of bands also occurs in crystalline compact materials

2 5 Metal Matrix Composites and Composite Foams

Since the investigation reported in this thesis deals with AlSiC foam, which is formed by foaming of aluminium silicon carbide metal - matrix composite, so for understanding the AlSiC foam, a brief description of MMC's is reported

2 5 1 Metal-Matrix-Composites (MMC's)

A composite is a material prepared from two or more different substances that retain their individual identities and properties Composites materials generally include constituents that complement each other and are compatible A structural composite is generally made up of a matrix phase and one or more reinforcement phase(s)

Matrix or base material may be a metal or non-metal, reinforced with agents such as fibers, whiskers and second phase particles The overall properties depend on the properties of individual phases, their relative amounts, geometrical arrangement and the interaction between the various phases Metal matrix composites are now a major field of research as they offer high strength, stiffness and environmental stability of the reinforcing agents These have evolved over the past 20 years The primary support for these

composites has come from aerospace industry, more recently from automotive, electronic, and leisure (sports goods) industries At the present time, aluminium, magnesium, nickel based alloys, and ferrous alloys are being used as matrix materials The aluminium based composites are the only ones that have become widely available and have excellent prospects on account of their low densities, corrosion resistance and availability of information regarding their manufacturability, shaping, service durability etc Various reinforcing materials such as alumina and SiC particulates are being used for these materials

2 5 2 Al-SiC Foam

Al-SiC foam is based on a metal matrix composite AlSiC foam has a closed cell structure and is made of aluminium matrix with SiC particles dispersed in it The cell walls have a complex microstructure (fig 2 5) consisting of non-uniform distribution of particles, voids and cavities as well as micro-segregation and precipitates resulting from dendritic solidification [1] This material was produced during early researches by bubbling air through molten aluminium (alloy) containing SiC particles [6] An Al-SiC alloy (unspecified composition) was used to make samples for this study The samples were provided by ALCAN and R&D labs (Kingston, Ontario, Canada) The bubbles float to the top surface of the composite to form closed-cell foam, which is then allowed to solidify This foam is very stable and is easily manipulated Adjusting the gas flow rate and other process parameters can control cell size of this foam Figure 2 4 shows the microstructure of samples with different relative densities produced using this technique

Al-SiC foam has an additional factor, namely the presence of SiC particles The presence of particulate matter in liquid foams alters the surface tension and leads to an increase in the viscous forces Consequently the resulting structure is not an equilibrium structure The cell structure is sensitive to the relative density of the foam The relative density for this foam is in the range of the 0 04 - 0 2] The SiC particles tend to lie close to the surface of the cell walls (figure 2 6) Consequently, the mechanical response of this foam is complex, which is explained in the following section

2 6 Mechanical Response of Al-SiC Foam

The mechanical response of Al-SiC foam is related to its cell structure and also to the microstructure of the material Al-SiC foam has an additional factor, namely the presence of SiC particles The role of SiC particles can be considered at the two levels Firstly, they alter the effective elastic properties of the cell walls and edges, thereby affecting the buckling and collapse loads An indirect effect on the buckling and collapse modes is through the effect of SiC particles on the cell structure of the foam samples In addition the particle may alter the behavior by introducing new failure mechanisms, such as interfacial debonding and particle cracking As described above that Al-SiC foam has a very heterogeneous microstructure in terms of distribution of SiC particles in the matrix, which needs to be considered in describing the mechanical properties

For understanding the mechanical response of the Al-SiC foam sample, there is need to understand the mechanical response of individual cell walls The load deflection response observed for a sample loaded with a steel ball [1] Figure 2 7 shows a deformed sample

The load deflection curve (figure 2 8) comprises of four stages

Stage I - The initial response is elastic, however the inhomogeneties present in the sample cause stress concentration and debonding at the particle matrix interface in the region close to the indentor (figure 2 9) This results in a serrated appearance of the load/deflection curve

Stage II Continued loading leads to rupture and tearing along the arrays of cracks, which are formed Figure 2 10 shows that material failure takes place in two stages, debonding at the particle matrix interface, followed by ductile tearing of the Al matrix

Stage III Continued tearing takes place at constant load As the deformation increases, a bulge (cap) forms in the central region Membrane forces acting in this region then come

into play so that the stiffness rapidly increases with increasing deformation, and tearing can continue only under an increasing load

Stage IV Once the cracks extend beyond a certain length, the stiffness decreases, resulting in a decrease in load As the crack progresses through the matrix or particle/matrix interface regions there is a fluctuation in load Mechanisms such as microvoid coalescence, debonding at particle/matrix interface, particle pullout etc can be identified in such regions (figure 2 11)

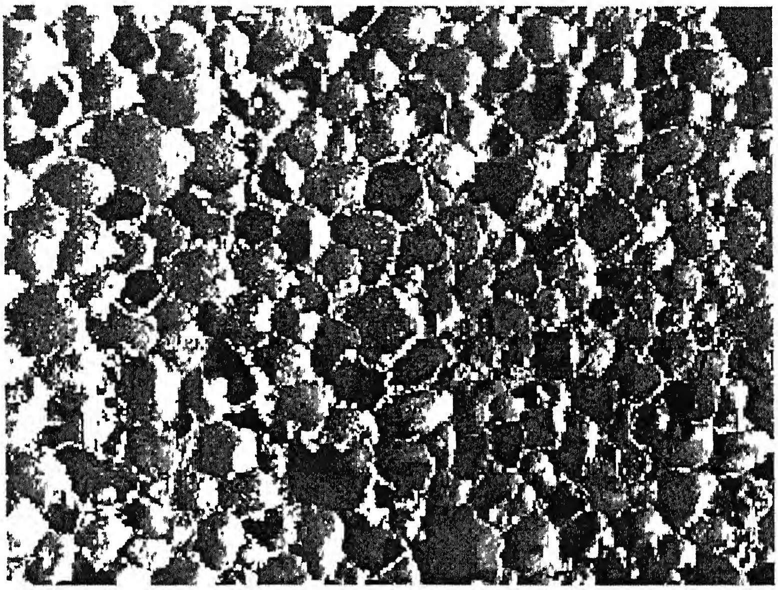


Fig 2 1 Pore structure of Al-SiC foam [11]

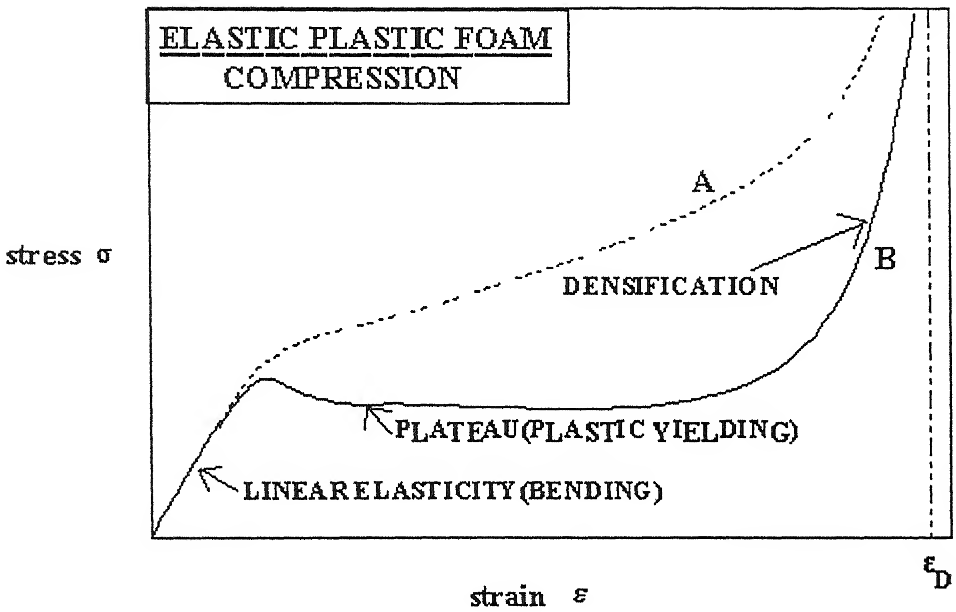


Fig 2 2 Deformation of foam under compression loading

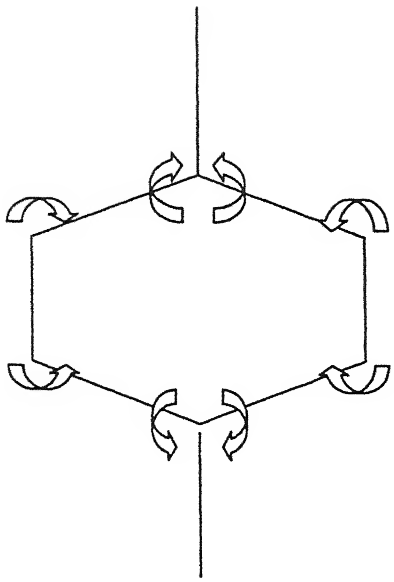


Fig 2 3a Open-cell foams- cell wall bendıng

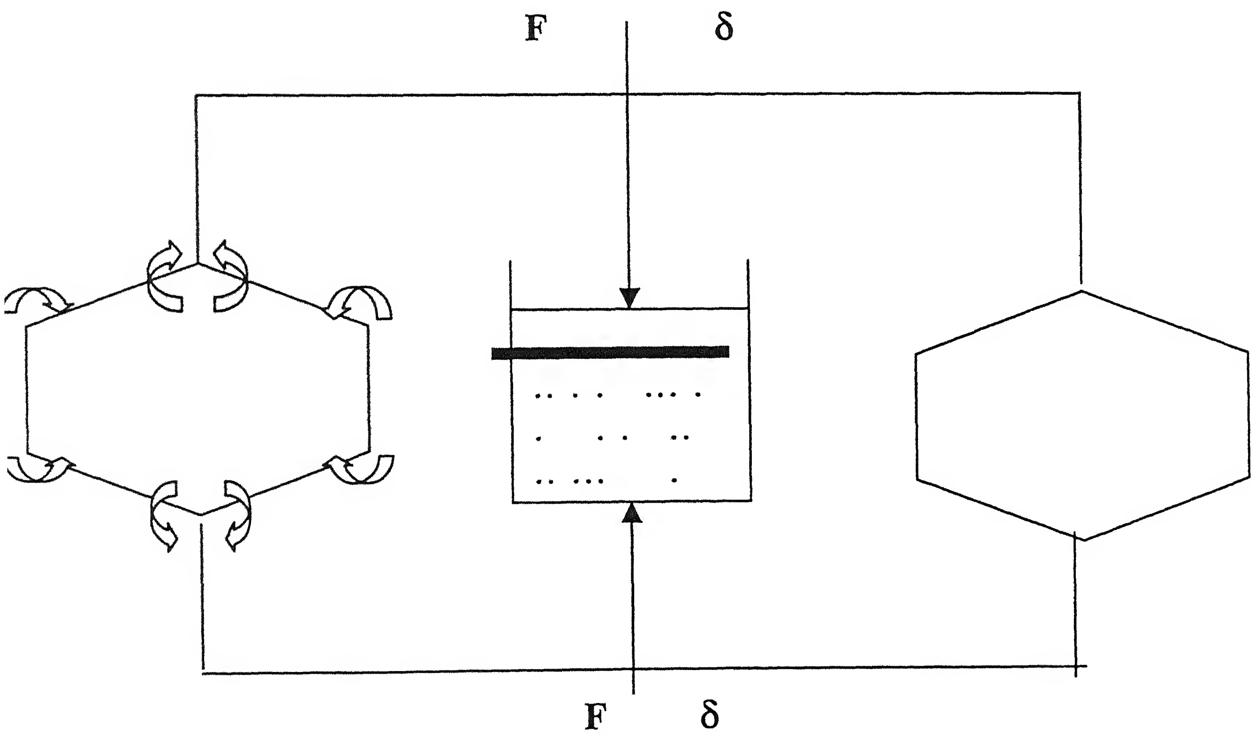


Fıg 2.3b Closed cell foams --- cell wall bendıng + enclosed gas pressure +membrane stretching

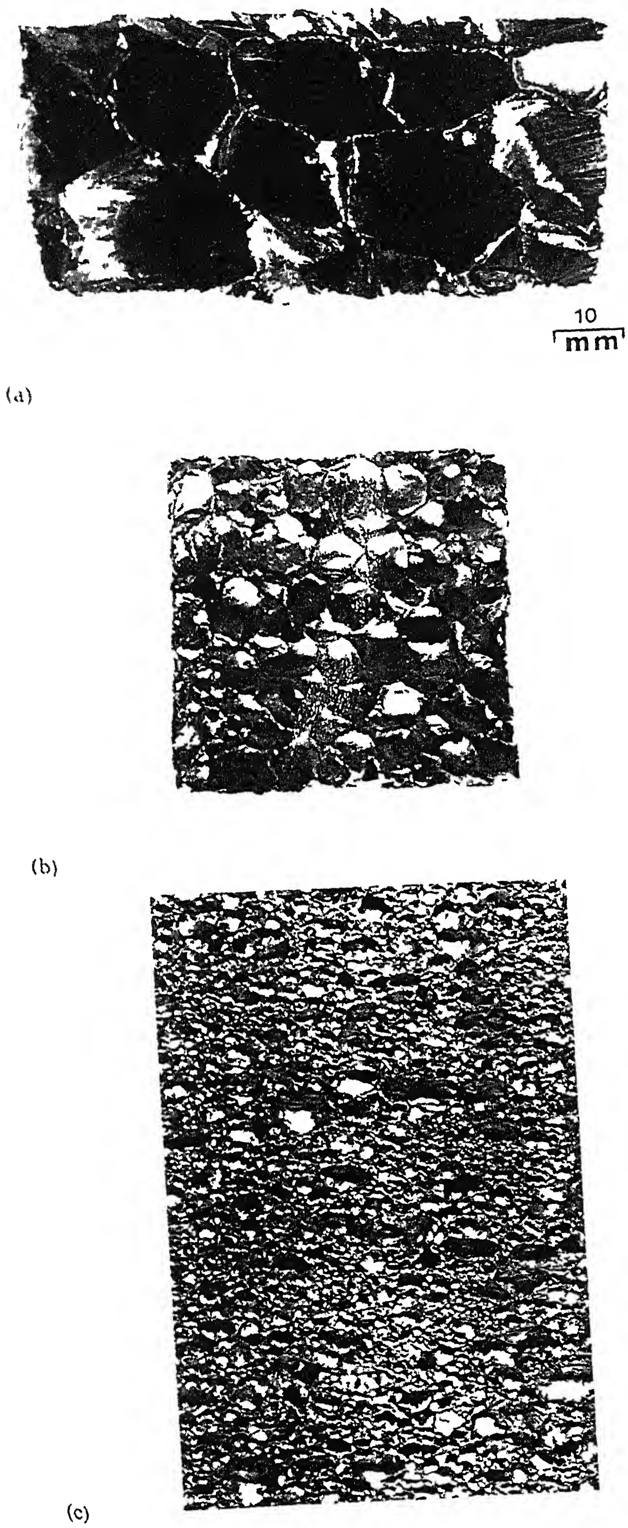


Fig 2 4 Macrostructure of Al-SiC foams with relative densities (a) 0 04, (b) 0 1, and (c) 0 2 [1]

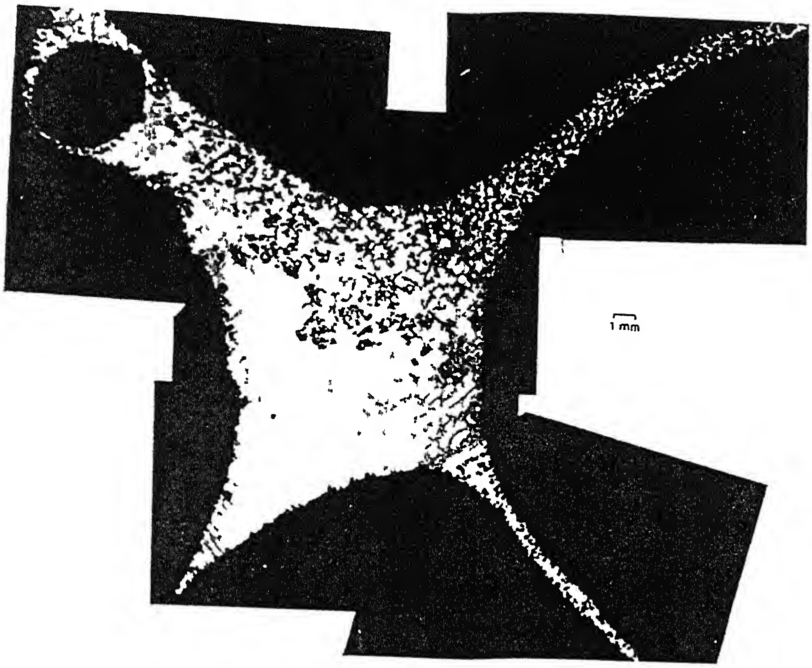


Fig 2 5 Optical micrograph of cell edges in Al-SiC foam showing distribution of SiC particles [4]

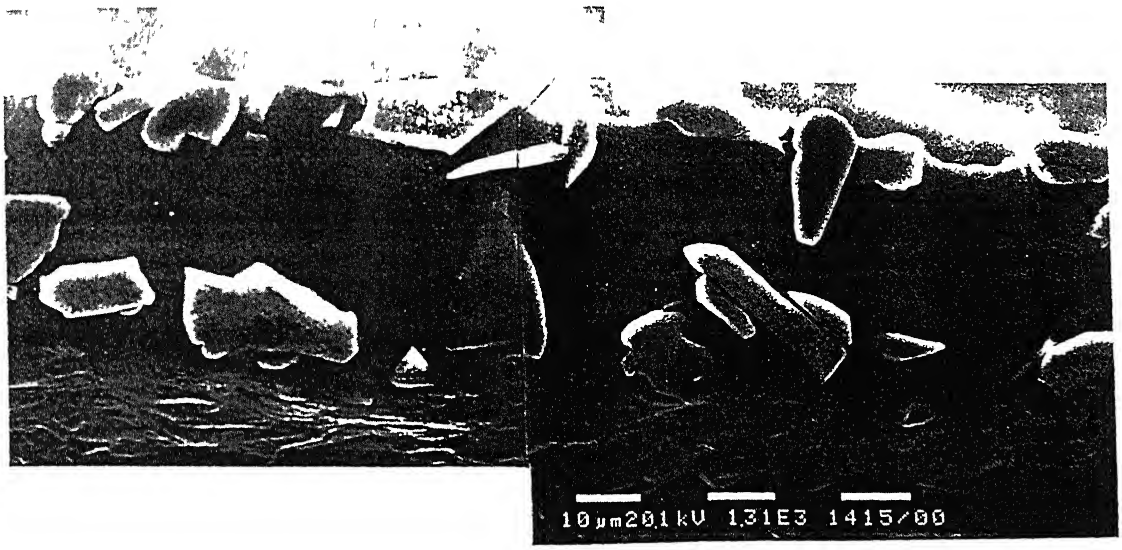


Fig 2 6 SEM micrograph showing distribution of SiC particles close to surface of a cell wall in Al-SiC foam [4]

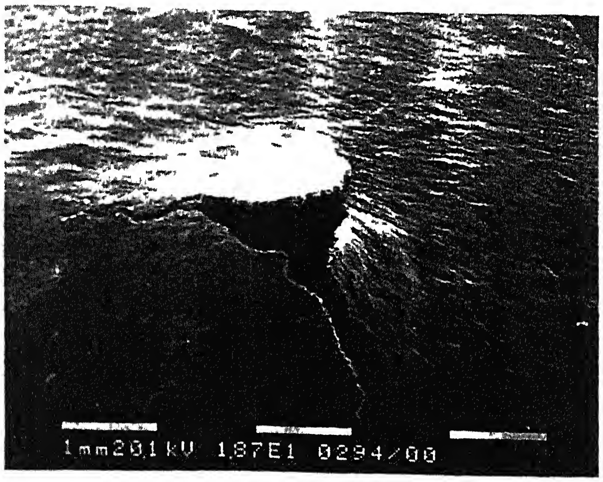


Fig 2 7 Rupture of a cell wall of Al-SiC foam under loading [1]

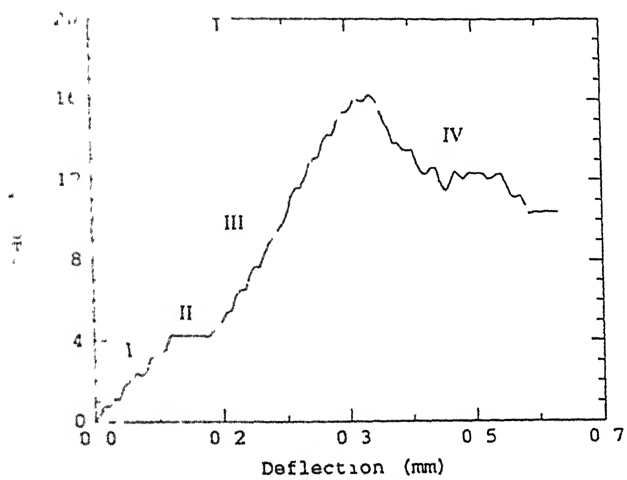


Fig 2 8 Load deflection response of a single cell wall of Al-SiC loaded in the center by a spherical indenter

Fig 2 9 Damage resulting in Al-SiC cell wall under the loading [1]

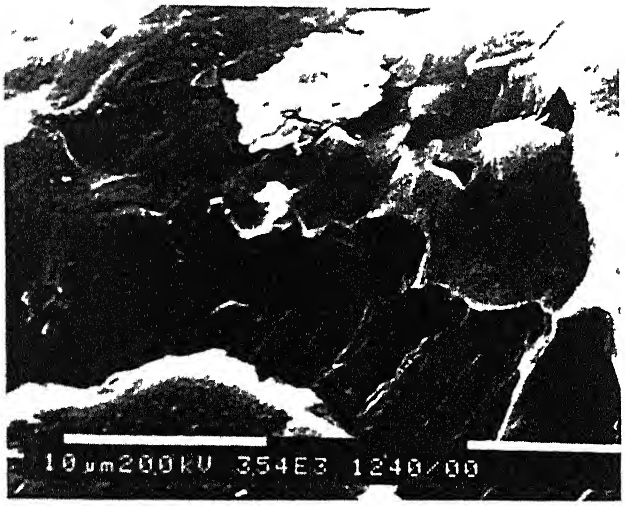


Fig 2 10 Debonding of Al-SiC interface and ductile tearing of the Al matrix [1]

Fig 2 11 Micrograph showing regions of ductile and interfacial failure in Al-SiC foam [1]

CHAPTER 3

EXPERIMENTAL DETAILS

The experimental details of the work reported in this thesis are described here

3 1 Specimen preparation

The specimens were prepared, from the block of the Al-SiC foam The specimens of 5 cm x 5 cm x 5 cm size were cut using a bandsaw
Since the surfaces of the block, which are to be held in compression, were not truly flat, the top and the bottom surfaces were polished with the emery paper to make them flat This ensures that cyclic compressive load (fig 3 1) will be taken uniformly by the top and the bottom surface

3 2 Machine set up

The machine used for compression and fatigue test has the following specifications The MTS 810 machine is shown in fig 3 2

MTS 810 (MATERIAL TEST SYSTEM)

Maximum load carrying capacity – 100 KN

Maximum Pressure – 21 MPa

In the set up, the test specimen was held in compression using the hydraulic wedge grip of the MTS machine Care was exercised to ensure that both the top and bottom surfaces are in perfect contact with the platens

3 3 Fatigue testing

For fatigue tests, the console was switched to the Load control mode The specimen was subjected to compressive cyclic load as shown in fig 3 1 The load was varied between (-1 33 KN and –1 KN) at a frequency of 5 cycles per second This cyclic loading continued up to desired number of cycles (typically 40,000 cycles)

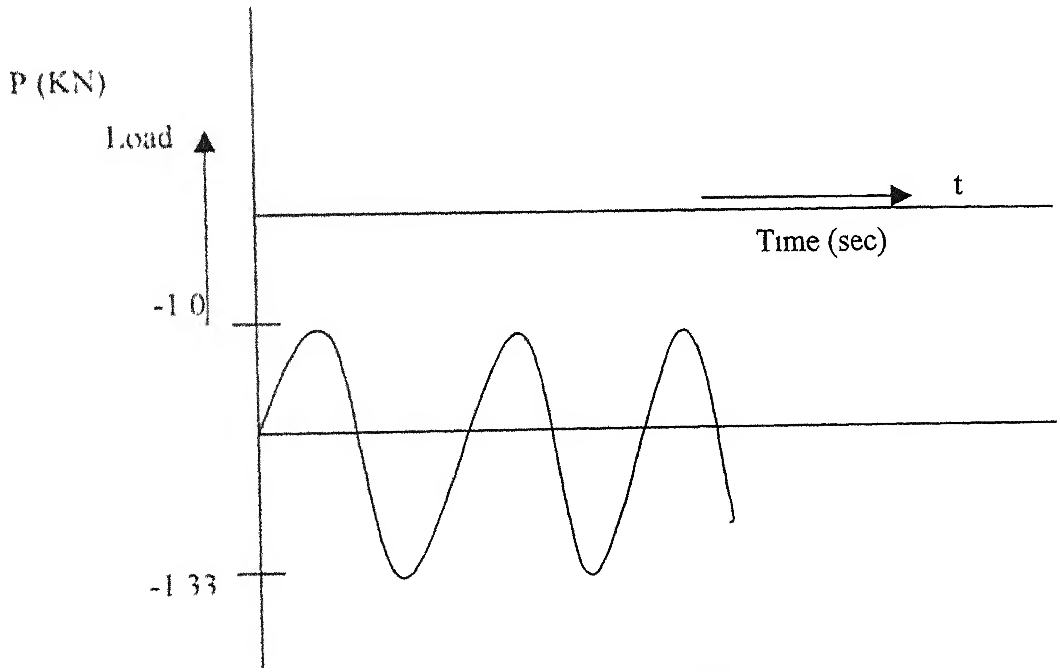


Fig 3 1 Cyclic loading

A maximum compressive load of 0 6 KN to 0 7 KN was applied at quasi-static loading state to the specimen held in the grips A plot of load versus deflection was recorded shown in Appendix

After this the specimen was unloaded and taken out from the machine for the measurement of its height, the height was measured with the help of vernier caliper The test was interrupted periodically to assess the damage in the specimen

The change in elastic modulus was used as a criterion for damage The elastic modulus was measured in displacement control

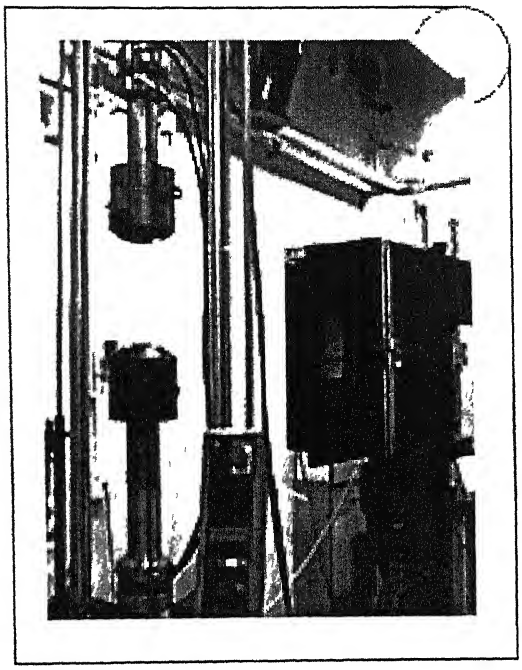


Fig 3 2 MTS 810 machine

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Compression Response of foam samples·

The compression response of Al-SiC foam was studied on 5 cm x 5 cm x 5 cm samples under fatigue loading (compression) The sequence of deformation events observed was elastic deflection of the cell elements followed by localized deformation in a few cells The formation of a deformation band shown in fig 4 1, collapse, densification of cells within this band, and gradual spreading of this band through the entire sample

The propagation of deformation band takes place through repeating cycles of yield, collapse and densification of cells and the load versus deflection curve (figure 4 2) give its characteristics appearance

4.1.1 Elastic response:

The initial response reflects the elastic deflection of the cell elements and is followed by localized yielding

4.1.2 Yield:

Based on the observations made on individual cell walls, the yield point constitute particle matrix debonding (fig 2.9 and 2 10) and local yield in regions where the stresses are maximum The stresses are expected to be maximum at the mid section of the longest and the thinnest cell edges The cell walls do not contribute to load bearing This was confirmed by puncturing many cell walls, and observing that this did not affect the strength properties of the foam Cell walls have a role to play in providing stability against the buckling of the edges, but buckling is not the major collapse mode in Al-SiC foam

4.1.3 Formation and growth of deformation band:

Once a set of cells has yielded geometrical constraints (continuity of deformation in neighboring regions) perturb the neighboring cells and lead to the formation of a deformation band The deformation band is found to be uniform for foam samples of relatively regular shape and size where localization takes place along a band in a cooperative manner (figure 4.1)

4.1.4 Collapse and densification:

The collapse of cell walls, following local yielding of cells in a deformation band, takes place through various mechanisms such as growth of interfacial cracks, and results in a decrease in the stress level Local densification is then required before the deformation may spread through adjoining cells

Failure thus proceeds in a sequential manner with repeating cycles of yield, collapse and densification This results in fluctuation of load, which is large for samples having a large distribution in cell size, but small for samples with uniform cell size For applications where it is desirable to prevent large variation in load, the cell size should be uniform

Initially, successive yield takes place at about the same stress level, but with the increasing strain there is some amount of global densification, which results in an increase in global stress The yield stress in the plateau region depends on the relative density of the foam, with denser foams having a higher yield stress In Al-SiC foam

local fracture of cell walls and edges take place through the formation of cracks at the interface in the Al-SiC foam

4 2 Fatigue response of foam samples

The specimen was subjected to relatively low stresses so that the damage accumulation is gradual The change in elastic modulus was taken as measure of damage in the specimen [13]

SR.NO.	SPECIMEN HEIGHT (mm)	NO.OF CYCLES (N)	MODULUS OF ELASTICITY (M
1	53 5	0	113 275
2	53 35	500	82 32
3	53 22	1200	83 40
4	53 05	1700	127 90
5	52 91	2200	124 73
6	52.80	2700	130 93
7	52 67	3200	380 95
8	52 52	3700	141 818
9	52 40	4200	144 38
10	52 28	5000	157 556
11	52 15	6000	82 29
12	52 03	7000	133 80
13	51 86	8000	145 03
14	51 60	9000	186 207
15	51 35	10000	180 07
16	51 10	11000	224.08
17	50.90	12000	218 16
18	50 75	13000	225 16
19	50 26	14000	226 26
20	50 10	15000	256.74

21	50 05	16000	240 75
22	50 00	17000	255 56
23	49 97	18000	279 11
24	49 83	19000	269 12
25	49 69	20000	263 56
26	49 51	21000	168.51
27	49 36	22000	178 50
28	49 20	23000	187 53
29	49 12	24000	213 12
30	49 00	25000	140 00
31	48 98	25500	88 60
32	48 92	26000	177 133
33	48 90	26500	157 193
34	48 86	27000	235 60
35	48 74	27500	388 045
36	48 69	28000	470 23
37	48 60	28500	437 45
38	48 55	29000	229 89
39	48 50	29500	467 72
40	48 45	30000	560 7
41	48 26	30500	209 44
42	48 02	31000	266 28
43	47.90	31500	284 86
44	47 70	32000	230 00
45	46 00	32500	92 42
46	45 80	33000	193 23
47	45 75	33500	171 41
48	45 70	34000	140 73
49	45 66	34500	292 53
50	45 62	35000	281 46
51	45 58	35500	350 11

52	45 55	36000	381 42
53	45 53	36500	609 10
54	45 51	37000	488 87
55	45 49	37500	216 21

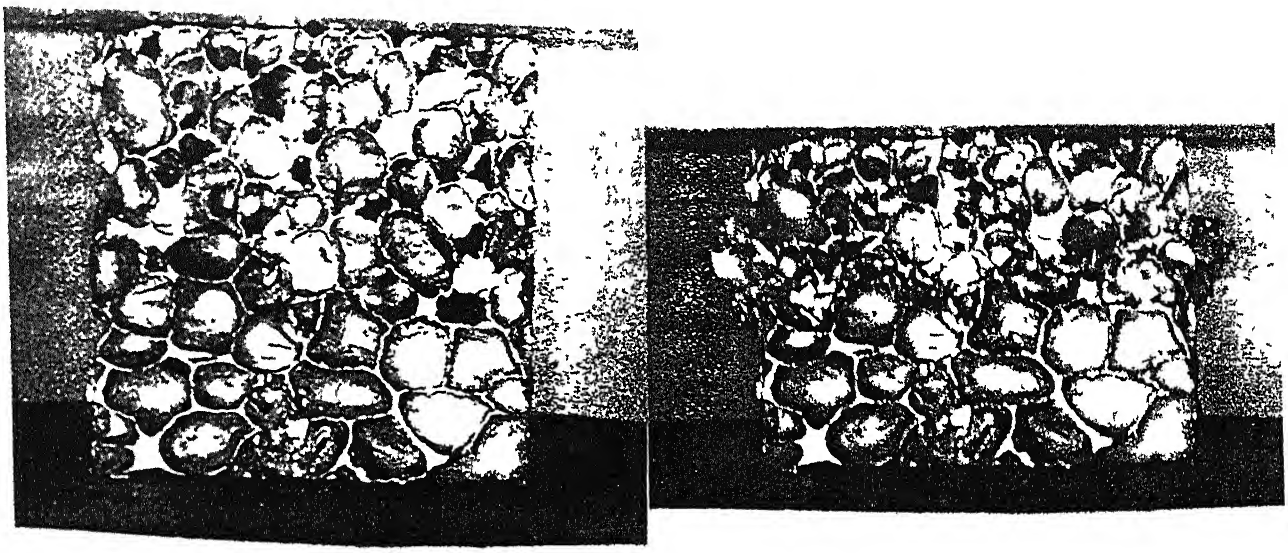
Table 4 1 shows the result obtained for a representative sample

The deformation suffered by the specimen as well as variation in elastic modulus (E) with the number of cycles of loading is shown in fig 4 3 and fig 4 4 It is observed that the deformation increases monotonically with gradual change in rate of deformation except a few sudden changes In contrast, elastic modulus (E) fluctuates widely

It was observed that, initially as the numbers of cycles were increasing there was rise and fall in the values of the modulus of elasticity (E), but "E" was increasing grossly The reason behind is that when we applying the load on the test specimen that is Al-SiC have closed cell structure, initially the load is taken by the cell wall and starts deforming The foam crush at an almost constant plateau stress until opposing cell faces touch, after then the stress-strain curve rises steeply, and densification occurs After the densification of the layer close to the surface, the cell wall material took the whole load, so due to this a high increase in the value of the "E" was observed

This phenomenon continues and due to these the value of "E" fluctuates sharply, until whole material becomes dense When whole cell wall intact then the material solidifies hence a sudden increase in the value of E observed The fluctuating trend in "E" is shown in Fig 4 4

The deformation in the material is also increasing as we increase the number of cycles Initially the deformation in the material starts linearly and increase monotonically in this way and again there is rise in the deformation This behavior is due to densification and stiffening of the cell walls Just before rupture there is a sharp increase in the deformation and once the material densified then it deforms very slowly till rupture



4 1 Figure shows the formation of a wavy deformation band in Al-SiC foam loaded in compression in the axial direction [1]

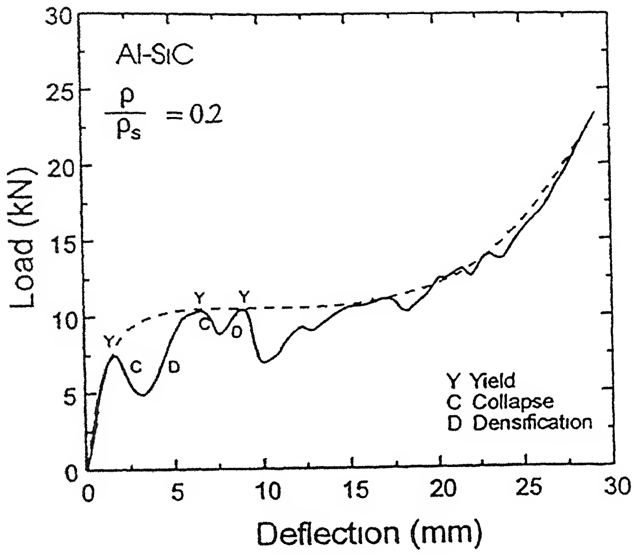


Fig 4 2 Load deflection curve for a closed cell Al-SiC foam

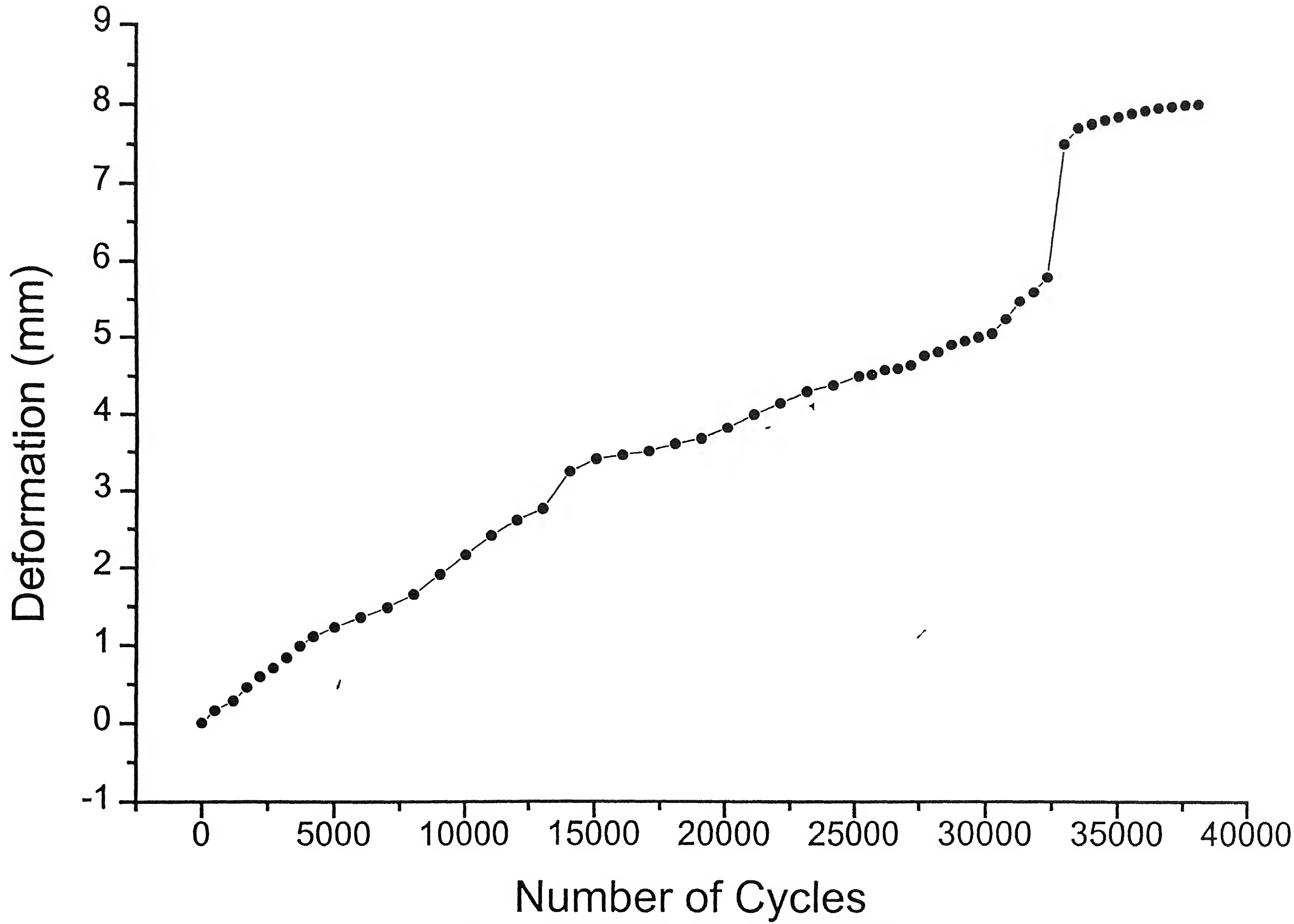


Fig 4 3 Plot of Deformation versus No of cycles

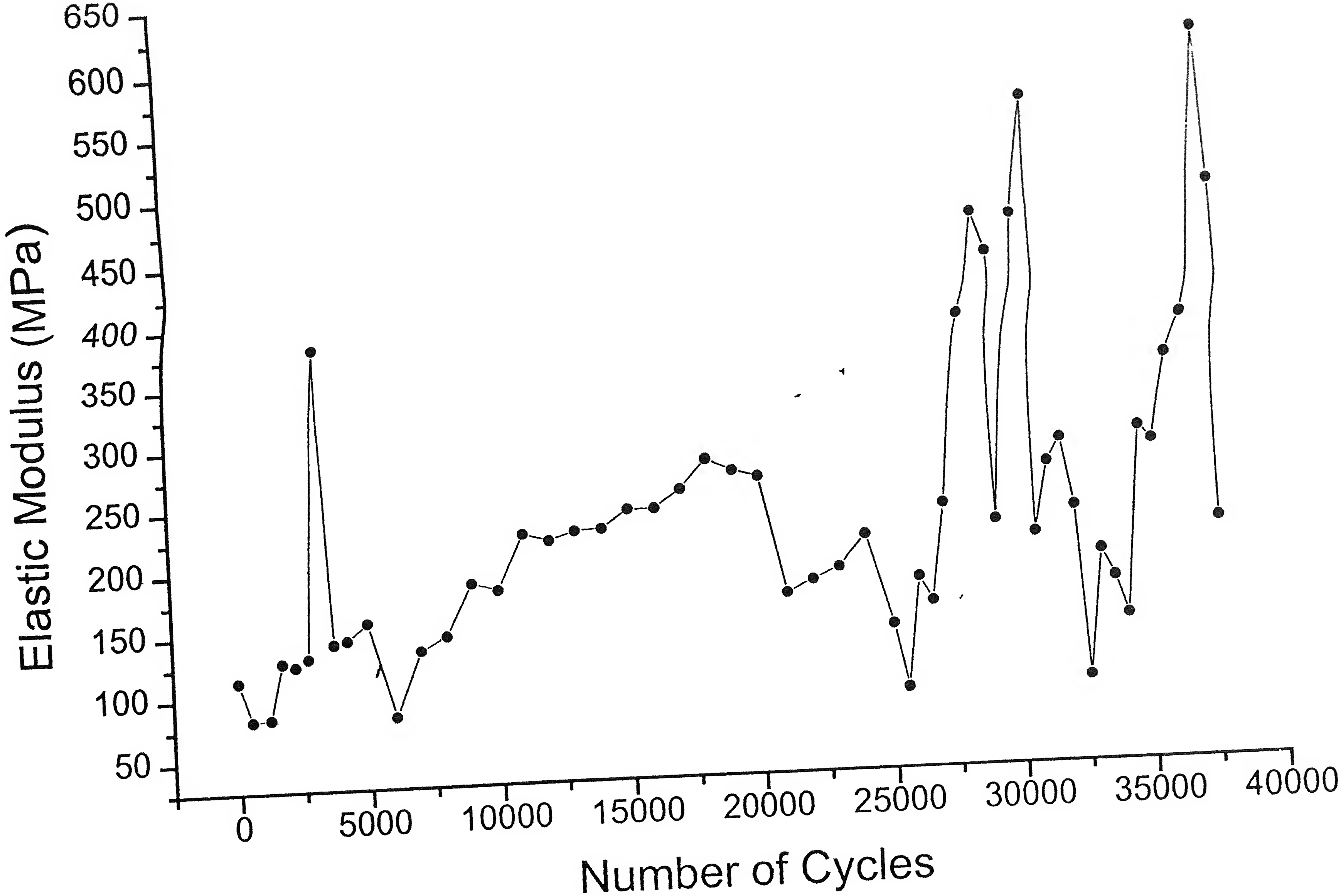


Fig 4.4 Plot of Elastic modulus versus No. of cycles

CHAPTER 5

CONCLUSION

5 1 Conclusion

This work has dealt with the fatigue behavior of Al-SiC foam An experimental study of fatigue of Al-SiC under compressive loading has been carried out The results indicate that the damage associated with such loading remains confined in a deformation band The deformation band gradually spreads through the sample with increasing number of cycles The process within the deformation band includes yield, collapse and densification of cells

Variation in “E” has been used as a measure of damage Since damage accumulates through yield, collapse and densification of cells within a deformation band, and since the band propagates once a layer of cells is fully densified, fluctuation in the value of “E” is obtained This is because partially collapsed cells within the deformation band lead to low “E”, whereas densified cells lead to high “E”

The major inference is that just like in compression loading, fatigue is characterized by localized deformation and although “E” tends to fluctuate, there is no major loss of overall stiffness This is of significance for packaging applications based on

cellulai solids, where low-stress fatigue of the packaging material must not lead to loss in overall stiffness

5 2 Scope foi future woik

The piesent work is on the fatigue analysis of Al-SiC foam under low compressive stresses The work should be extended to observe its fatigue behavior under large compressive stresses

Further work can be done on Al-SiC foam to observe its fatigue behavior under tensile and shear load

References:

1 Structure and properties of Al-SiC foam O Prakash, H Sang, J D Embury *Material Science and Engineering A 199 (1995) 195-203*

2 H P Degischer, Materials Des 18 (1997), pp 221-226

3 B L Ruskin, Handbook of foamed plastics, Lake publishing, Libertyville, 111, 1965, Chap XIV

4 Cellular Solids – Structure and properties Lorna J Gibson & Michael F Ashby *Pergamon Press*

5 Shapovalov, Method for manufacturing porous articles, U S Patent No 5,181,549,1993

6 I Jin, L D Kenny and H Sang, US patent No 5,112,697,1992.

7 M E Rosa and M A fortes, Journal of Material Science, 26, 1991, pp341

8 P H Thornton and C L Magee, Deformation of Aluminum Foams, Met Trans , Vol 6A, 1975, pp 1253

9 L J Gibson, M F Ashby, J Zhang and Triantafillou, International journal of mechanical sciences, 31, 1989, pp 635

10. M F Vaz and M A Fortes, Journal of material sciences, letters, 12,1993, pp1408

11 Fatigue properties of aluminium foams at high numbers of cycles B Zettl, H Mayer, S E Stanzl-Tschegg, H P Degisher *Material Science and Engineering A292 (2000) 1-7*

12. Fatigue failure of an open cell and a closed cell aluminium alloy foam
A M Harte, N A Fleck and M F Ashby *Acta materllurgica inc Vol 47,No 8, pp 2511-2524, 1999*

13 Damage mechanics H J Frost and M F Ashby
Pergamon Press

14 On the mechanical performance of closed cell Al alloy foams
Y Sugimura, J Meyer, M Y He, H Bart-Smith, J Grenstedt and A G Evans *Acta materllurgica, Vol 45, No 12, pp 5245-5259, 1997*

15 Deformation Heterogeneity in Cellular Al alloys
Ashraf-F Bastawros and Anthony G Evans *Advanced Engineering Materials, Vol 2 No 4, pp 1438-1656, 2000*

Appendix

In this experiment, the cyclic load is applied with increment of 500 cycles after each reading For each reading the value of load and deformation is shown on micro console and the plotter is used to plot the deformation of Al-SiC foam with respect to the applied load It is easy to calculate the value of load and deformation with the help of these plots by applying the suitable scales used for calculation

Scale used for load

1V = 1 KN

Plotter Speed

0 05 V/cm

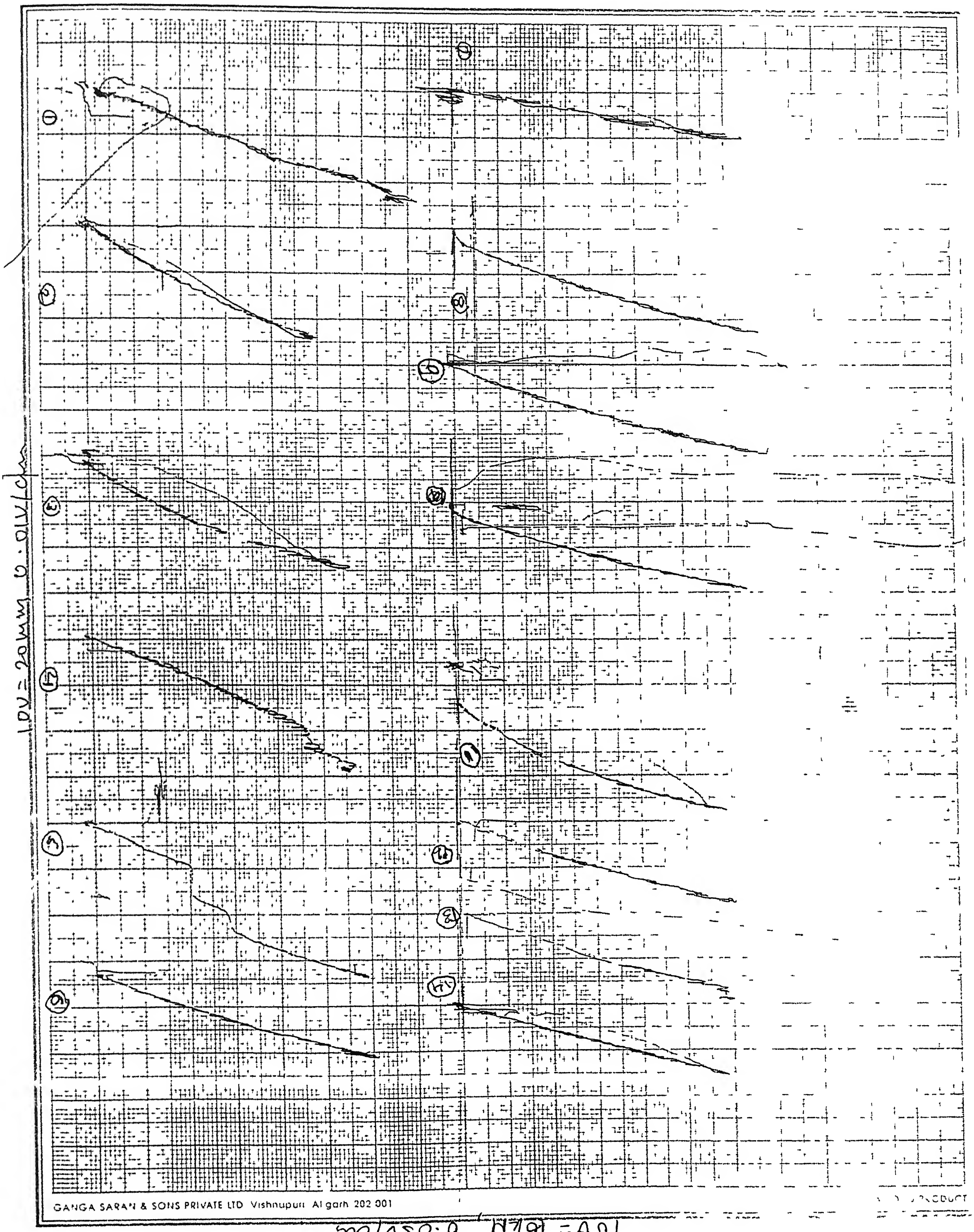
Scale used for deformation

1 V = 2mm

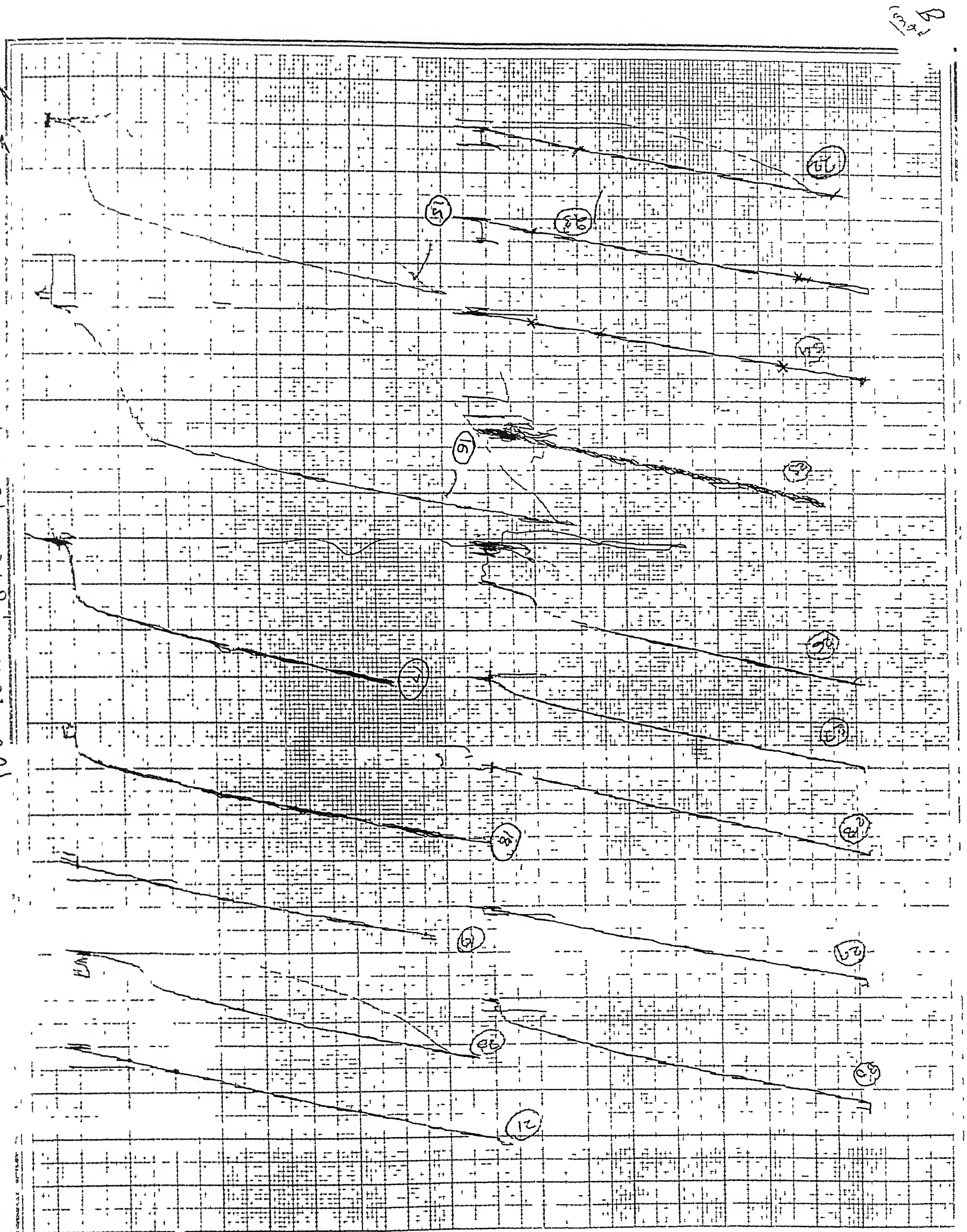
Plotter speed

0 01 V/cm

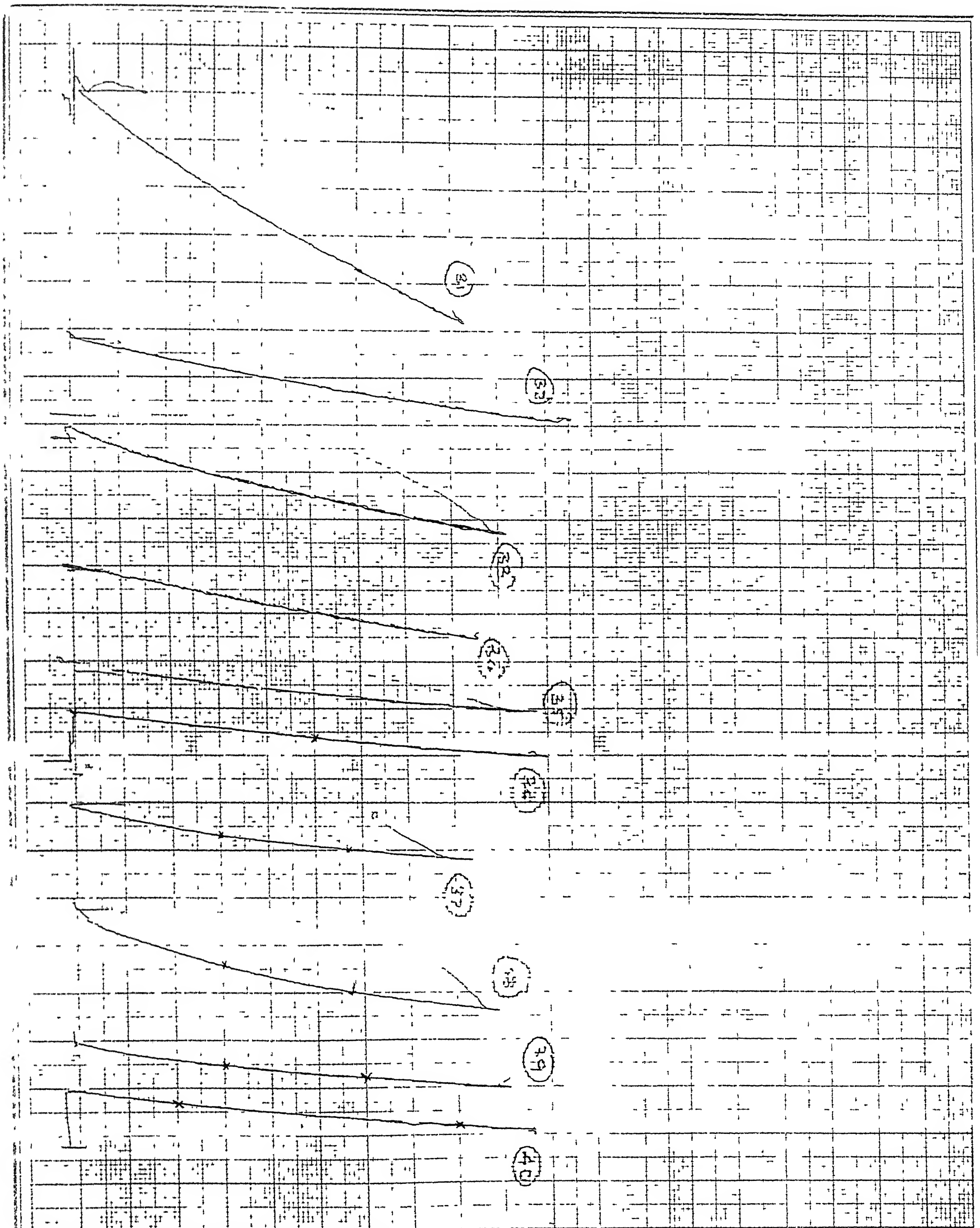
FOR PART (B)



1.0V = 20mm 0.01V/div
GANGA SARAN & SONS PRIVATE LTD Vishnupuri Aligarh 202 001
10V = 16cm, 0.05V/cm



GANGA RAM & SONS PVT LTD Vishnupuri Aligarh 202 001 A DIAMOND PRODUCT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